Detecting the Effects of Wars in the Caucasus Regions of Russia and Georgia Using Radiometrically Normalized DMSP-OLS Nighttime Lights Imagery

Frank D. W. Witmer and John O'Loughlin[1]
Institute of Behavioral Science, University of Colorado,
Boulder, Colorado 80309-0483

Abstract: Satellite data can provide a remote view of developments in often dangerous conflict zones. Nighttime lights imagery from the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (DMSP-OLS) satellite was used to detect the effects of war in the Caucasus region of Russia and Georgia. To assess changes over time, the data were radiometrically normalized using cities with a relatively stable nighttime lights signature over the course of the study period, 1992–2009. Buffers were created around these stable cities to select the pixels that were then used to normalize cities and towns whose nighttime lighting fluctuated over time. The results show that conflict-related events such as large fires that burn for weeks and large refugee movements are possible to detect, even given the relatively coarse spatial resolution (2.7 km) of the DMSP-OLS imagery.

INTRODUCTION

Violent conflict often creates environments hostile to journalists and researchers trying to understand and report events on the ground. Remotely sensed imagery has the potential to corroborate reports of unknown quality that emanate from war zones. High-spatial-resolution imagery can confirm some types of violence, such as destroyed structures in Sudan (USHMM, 2009) or Georgia (UNITAR, 2008a; AAAS, 2010), but is often expensive and its acquisition may be delayed depending on satellite position and scheduling. In this paper, we use nighttime lights satellite imagery to detect the effects of violence in Russia and Georgia on both sides of the Caucasus Mountains. We explore the trend in nighttime lights for the long-term conflict in and around Chechnya in the North Caucasus of Russia and the short, but intense, war in South Ossetia (a separatist area of Georgia) in August 2008. Though these conflicts differ in many ways, both conflicts resulted in large refugee movements during and after wars characterized by intense bombing campaigns.

Examining the effects of violence on nighttime lights from these two neighboring conflicts allows us to apply our methodology in different national and conflict settings and test the sensitivity of nighttime lights satellite imagery to varying duration of

---

[1] Email: witmer@colorado.edu; johno@colorado.edu

GIScience & Remote Sensing, 2011, **48**, No. 4, p. 478–500. http://dx.doi.org/10.2747/1548-1603.48.4.478
Copyright © 2011 by Bellwether Publishing, Ltd. All rights reserved.

violence. That the conflicts occur in different countries and show a different character complicates the analysis due to differing national norms, wealth, and levels of lighting. The North Caucasus conflict is a long running civil war, or more accurately, a set of connected civil wars (O'Loughlin and Witmer, 2011), while the South Ossetian 2008 war was short in duration, but international in scope.

There is a growing body of research using remote sensing imagery to study conflict and its effects on the natural and built environment. Multiple sensors, from relatively coarse AVHRR imagery to finer spatial resolution Landsat and SPOT data were used to document the effects of the 1991 Gulf War in terms of oil lakes, burning oil wells, and military vehicle movements (Williams et al., 1991; Stephens and Matson, 1993; El-Baz and Makharita, 1994; Husain, 1994; Kwarteng, 1998). Satellite imagery has also been used to document more recent conflict in Iraq, such as the trench oil fires around Baghdad in 2003 (UNEP, 2003) and the war effects on the Mesopotamian Marshlands (UNEP, 2010).

The recent conflict in Sudan has spurred multiple studies using satellite imagery to document and even try to prevent violence by monitoring villages (Spotts, 2010) or examining changes in vegetation health (Brown, 2010). Most of the detection efforts aim to identify destroyed villages (detectable due to missing/burned roofs) using high-spatial-resolution Quickbird imagery (USHMM, 2009; Sulik and Edwards, 2010), though Landsat ETM+ data are also capable of detecting changes in albedo associated with burned villages (Prins, 2008). The Satellite Sentinel Project recently identified the destruction of the village, Tajalei, and drew widespread attention to it (Kron, 2011; Satellite Sentinel Project, 2011). A Yale University project used MODIS and SPOT imagery to show how the violence in Darfur allowed vegetation to recover in agrarian and livestock grazing ranges as humans and livestock were forcibly displaced (Schimmer, 2008).

The effects of conflict on vegetation have also been documented elsewhere using satellite imagery. In northern Sri Lanka, prolonged violence has affected land use (reduced agricultural activity and an increase in rangelands) via population displacement, landmine placement, and security zone enforcement (Suthakar and Bui, 2008). Similar factors of ethnic cleansing and collapsed markets resulted in agricultural land abandonment in Bosnia-Herzegovina from the 1992–1995 war (Witmer, 2008). During the early 1990s, the Turkish army actively burned forests in eastern Turkey as part of an effort to undermine the livelihoods of the ethnic Kurds living there and combat Kurdish separatist support. Landsat imagery analysis from before and after the fires was able to confirm their extent and corroborate eyewitness reports (van Etten et al., 2008). Population displacements due to war in Uganda are also documented using high-resolution Quickbird, WorldView-1, and IKONOS imagery (Joiremon, 2012).

In detecting the effects of war on nighttime lighting, many aspects such as individual explosions and deaths often do not directly affect the detectable nighttime lights signature, but other outcomes such as refugee movements, power grid damage, and fires can be expected to show a visible signature. We first provide a contextual accounting of both conflicts, with an emphasis on events that affect nighttime lighting, before describing the data and methods used to evaluate the trends in nighttime light levels. We then examine the utility of this methodology for the Caucasian wars over the past two decades and consider its wider potential as an aid in the field of conflict studies.

North Caucasus Wars

In the North Caucasus of Russia, rebels and government forces have fought two wars since the mid-1990s. The first Chechen war, from 1994 to 1996, was confined to Chechnya, especially its capital city, Grozny. During this conflict, the central part of Grozny was heavily damaged and an estimated 40,000 civilians were killed with another 250,000 displaced, many to neighboring Ingushetia (Zürcher, 2007). The second Chechen war began in August of 1999, and though Russia officially ended its counter-terrorism operations in April 2009, violence is still common in Chechnya while increasing in the neighboring republics of Ingushetia and Dagestan (BBC News, 2009; Mendelson et al., 2010; O'Loughlin et al., 2011). The second war brought considerable bombing to Grozny and other urban areas as Russian forces altered their tactics from the first war to reduce on-the-ground resistance for their infantry. This approach devastated Grozny and caused nearly all civilians to flee, reducing its population from almost 400,000 people to an estimated 40,000 or fewer (Zürcher, 2007).[2] Nichols (2000, p. 246) described the destruction in Grozny as the greatest "ever visited on any urban area in any non-nuclear war." The intense fighting also resulted in the destruction of power stations and electrical transmission lines (ITAR-TASS, 1995, 1999b; RIA Novosti, 2000), heavy damage to 70 percent of the roads (Vendina et al., 2007), and the ignition of dozens of oil wells (ITAR-TASS, 2000; Vatchagaev, 2008).

The first war followed Chechnya's 1991 unilateral declaration of independence and is often described as a nationalistic struggle for a secular, independent state. By contrast, the current conflict (post-1999) has taken on the goal of erecting a pan-Caucasian Islamic state after Chechen nationalistic mobilization collapsed along with the state apparatus during the inter-war years, 1996–1999. These characterizations, however, oversimplify the diverse ethnicities, clan structures, criminality, and cultural variation of the region (Zürcher, 2007; King and Menon, 2010). Taken together, these North Caucasian conflicts have killed more than 75,000 civilians since 1994, according to the Russian human rights organization, Memorial (Kavkazskiy Uzel, 2007).

The conflict in the North Caucasus has been concentrated primarily in the Republic of Chechnya, but since the most intense fighting ended (in 2002), the conflict has diffused spatially, but less intensely, to the neighboring republics of Ingushetia and Dagestan (Fig. 1). This diffusion process can be seen visually from analysis using a violent event database with over 14,000 entries (O'Loughlin and Witmer, 2011).[3]

Though both Chechen wars resulted in hundreds of thousands of refugees, the destruction of housing was more limited in the first war (except for Grozny), allowing many of the internally displaced to return home after temporarily living with relatives and friends. For the second war, refugee trends were better documented by the UN High Commissioner for Refugees (UNHCR) and the Danish Refugee Council and showed that refugees remained displaced for many years. During the height of the initial bombing of Grozny during the fall of 1999, an estimated 254,000 refugees fled to neighboring Ingushetia (UNHCR, 1999). Three years later 110,000 Chechens remained displaced (UNHCR, 2002). Some estimates are as high as 600,000 residents

---

[2] The population of Grozny has now recovered to 250,800 as of January 2010 (Russian Federation Federal State Statistics Service, 2010), still considerably less than its pre-war population.

[3] These violent events were collected from media reports and geocoded using latitude and longitude coordinates for the nearest town.

Fig. 1. Locations of political units, key cities, and towns mentioned in the paper.

displaced since 1999, some for a second time (Holland, 2004). Registration data showed that by the summer of 2002, most of the refugees (56 percent) still lived with host families, while 21 percent lived in tent camps and 23 percent in spontaneous settlements (e.g., farm buildings and railway cars) (Danish Refugee Council, 2002). Many of these tent camps were quite basic, especially the first winter—the Alina camp in Sleptsovsk (Fig. 1) was the first to receive winterized tents with electricity in December 2000 (UNHCR, 2000). Refugees were encouraged to leave the tent camps starting in 2002, with the last of the tent camps dismantled in 2004, but only 142 houses were constructed in Ingushetia between 2001 and 2006 to accommodate remaining refugees (Soboleva, 2007). The latest figures estimate that 80,000 people from Chechnya are still displaced, at a time when regional violence was on the increase (Norwegian Refugee Council, 2009).

South Ossetian War

The duration of the violence in South Ossetia was much shorter, August 7–12, 2008. In the "five-day war" (Asmus, 2010), the city of Tskhinval(i)[4] (Fig. 1) and surrounding villages experienced heavy fighting as Russian and Georgian forces battled

---

[4] We use 'Tskhinval(i)' to reflect that the Georgian spelling is "Tskhinvali," whereas the Russian and Ossetian spelling is "Tskhinval." Similarly for Sokhum(i) below.

to control the disputed territory. As with the Chechen conflict, the war in South Ossetia stems from the break-up of the Soviet Union, after which Georgian nationalists gained influence and a period of violence between ethnic groups ensued in Georgia. This resulted in a counter-mobilization of Ossetian nationalists and attempts to elevate South Ossetia's independence from Georgia to unify with North Ossetia (Zürcher, 2007). In 1991 and 1992, three separate attempts by Georgia to seize Tskhinval(i) were repelled by South Ossetian militias. These initial battles set the stage for a period of increased tension between Russian-backed South Ossetia and Georgia, culminating in the summer of 2008 over disputes of airspace activity and clashes on the ground (Ó Tuathail, 2008).

Details of the start of the war are still in dispute, but heavy fighting was reported on August 7, 2008 between Georgian and South Ossetian forces, which quickly escalated as Russia sent tanks and troops from Vladikavkaz (north of the mountains) to assist the South Ossetians. The initial battle was for Tskhinval(i), the regional capital of South Ossetia, and neighboring mountain villages. Russian forces then moved southward to Gori (stopping short of the Georgian capital, Tbilisi) targeting primarily military installations (Ó Tuathail, 2008). In addition to the damage caused by military fighting, looters also contributed by stealing appliances such as TVs and refrigerators. As Russian tanks began withdrawing, South Ossetian forces destroyed ethnic Georgian villages east of Tskhinval(i) and along the road north to Russia (e.g., Kurta) in an effort to discourage Georgians who fled from returning to South Ossetia (Wendle, 2008; Human Rights Watch, 2009). Fires associated with this destruction were detected by MODIS satellite imagery in the weeks following the initial conflict (UNITAR, 2008b). "Domicide" (house destruction) efforts against ethnic Georgians were complete as seen in the villages along this road that remain decimated as of March 2010 (Fig. 2).

The five-day war displaced 127,000 people within Georgia proper (the area excluding Abkhazia and South Ossetia) and another 30,000 within South Ossetia (UNHCR, 2008), though many of these refugees were able to return within a few months following the cessation of violence (Sunjic, 2008). As of August 2010, 26,000 displaced people (nearly all ethnic Georgians) are still unable to return to South Ossetia (Amnesty International, 2010). There were several forest fires started as a result of air raids, affecting 1,000 ha of forest, though these fires were short-lived compared to the oil fires in Chechnya (Snoy et al., 2008). Power outages also occurred during the fighting, but even for the hard-hit city of Tskhinval(i), power was restored by the end of August 2008 (Ekho Moskvy Radio, 2008).

NIGHTTIME LIGHTS DATA

The Defense Meteorological Satellite Program (DMSP) first launched its Operational Linescan System (OLS) sensor in 1972 with a photomultiplier tube (PMT) capable of detecting moonlit clouds at night. In 1992, the Air Force Weather Agency (AFWA) began sending digital data to the National Oceanic and Atmospheric Administration (NOAA) for archiving at the National Geophysical Data Center (NGDC). The PMT of the DMSP-OLS sensor allows detection of lights emitted from ground sources, with the most usable data collected during the darkest half of the lunar cycle when there is little interference from moonlight. Data are recorded at a ground sample distance of 2.7 km and resampled to a 30 arc second grid (Elvidge et al., 1999,

Fig. 2. A typical street in the village of Kurta, located in the South Ossetia separatist area of Georgia (Fig. 1). Photo taken by John O'Loughlin, March 2010.

2004) which, for the Caucasus latitudes, yields a spatial resolution of about 700 × 900 m (*x*, *y*). For this analysis, monthly and annual composites obtained[5] from the NGDC were created from the best usable nighttime data; they were selected from the center half of the 1500 km orbital swath, exhibited no sunlight, moonlight, solar glare, or auroral emissions contamination, and were cloud-free (Elvidge et al., 2009b). Note that for most years since 1992, two satellites (out of a group of five, including satellite numbers F10, F12, F14, F15, and F16) were operating simultaneously collecting nighttime lights imagery. To minimize the effects of sensor degradation, only data from the more recent satellite for any given month and year were used.

At the country scale, these nighttime lights data (lit area) are strongly correlated with population, economic activity (GDP), electric power consumption, and CO_2 emissions (Doll et al., 2000; Elvidge et al., 1997). Sutton et al. (2007) show that the relationship between lights and GDP also holds at the subnational scale for India, China, Turkey, and the United States. Additional subnational research used the relationship between nighttime lights and economic activity to predict the inflow of remittances to India not included in official state measures (Ghosh et al., 2010a). More recently, the strong relationship between nighttime lights and wealth has enabled the creation of global poverty and economic activity maps using the Landscan population grid data (Oak Ridge National Laboratory, 2008) coupled with nighttime lights imagery, land cover data, and topography (Elvidge et al., 2009a; Ghosh et al., 2010b). In contrast to the country or subnational units of analysis used in many of these studies, we are interested in war-related changes in lighting over much smaller areas such as cities and

---

[5] Monthly composite data must be purchased, but annual composites may be downloaded at no charge through http://www.ngdc.noaa.gov/dmsp/downloadV4composites.html.

Table 1. Russian North Caucasus City Census Data

City	Population		Percentage change
	1989	2002	
Budennovsk	55,262	65,687	18.9
Buynaksk[a]	56,673	61,437	8.4
Derbent	77,851	101,031	29.8
Essentuki	76,711	81,758	6.6
Georgiyevsk	62,476	70,575	13.0
Grozny	397,258	210,720	–47.0
Kaspiysk	60,010	77,650	29.4
Khasavyurt	70,053	121,817	73.9
Kislovodsk[a]	106,366	129,788	22.0
Makhachkala	314,767	462,412	46.9
Mineral'nyye Vody	69,283	75,644	9.2
Nal'chik[a]	230,641	274,974	19.2
Nazran'	18,076	125,066	591.9
Nevinnomyssk[a]	120,863	132,141	9.3
Pyatigorsk[a]	124,969	140,559	12.5
Stavropol'[a]	316,704	354,867	12.1
Vladikavkaz[a]	298,692	315,608	5.7

[a]City used to normalize nighttime lights data.

villages. Also, because we anticipate changes in the *amount* of city light, not just lit area, we use mean city light intensity for our metric.

Before looking for trends in nighttime lights associated with war-related activity and population movements, we first establish the relationship between population and nighttime light intensity for the largest urban areas in our study area. Table 1 shows Russian cities in the study area with a population greater than 50,000 in 2002 (Perepis, 2002) and Table 2 shows Georgian cities with a population greater than 20,000 (National Statistics Office of Georgia, 2010; Rowland, 2006). Locations for many of these cities are shown in Figure 1.[6] Note that the population numbers reported by the 2002 Russian census are highly suspect for Grozny. According to a 2000 survey conducted by the Danish Refugee Council (Trier and Deniev, 2000), just 67,212 people resided in Grozny, about one-third as many as reported two years later by the Russian census.

To quantify the relationship between population and nighttime lights, we plot the mean digital number (DN) for each city against its 2002 census population (Fig. 3). The area of each city was delineated using populated places polygons from the Digital

---

[6] For additional maps of place names, land cover, topography, and ethnic distribution of the Caucasus region, see (O'Loughlin et al., 2007).

Table 2. Georgia City Census Data

City	Population		Percentage change
	1989	2002	
Batumi	136,930	121,806	–11.0
Gori	67,787	49,516	–27.0
Khashuri[a]	31,717	28,560	–10.0
Kutaisi	232,510	185,965	–20.0
Marneuli[a]	27,065	20,065	–25.9
Poti	50,569	47,149	–6.8
Rustavi	159,016	116,384	–26.8
Samtredia[a]	34,255	29,761	–13.1
Senaki[a]	28,938	28,082	–3.0
Sokhum(i)	121,406	43,716	–64.0
Tbilisi	1,243,150	1,073,345	–13.7
Telavi	27,848	21,805	–21.7
Zestafoni[a]	25,891	24,158	–6.7
Zugdidi	49,614	68,894	38.9

[a] City used to normalize nighttime lights data.

Chart of the World (DCW) project (Danko, 1992). Because these polygons were constructed in the 1970s, we expanded them using a 5 km geographic buffer to account for population growth as well as data artifacts such as the coarse pixel size and geospatial location errors. To match the population data as closely as possible, the annual composite for 2002 (from satellite F15) was used.

We modeled the relationship using linear regression of the log transformed population to predict the nighttime lights intensity. The transformed linear fit line (R^2 = 0.70) is plotted in Figure 3 against the 17 Russian cities (blue) and 14 Georgian cities (red). For any given city population, the Russian cities are always brighter, reflecting, in part, the greater wealth generally found in Russia ($2,100 GNI/capita) compared to Georgia ($730 GNI/capita) for the year 2002 (World Bank, 2009). Note that dropping the large capital city of Tbilisi does not change the model much, with a slight improvement in overall fit (not shown).

Though the model does not explicitly capture differences in lighting associated with wealth, the analysis establishes a strong relationship between population size and nighttime light intensity. And due to the nonlinear relationship, an influx of refugees is likely to have a greater impact on nighttime lights in small towns rather than in larger cities, assuming the influx is accompanied by additional electrified housing.

CHANGE DETECTION USING NIGHTTIME LIGHTS IMAGERY

Few studies have used the nighttime lights imagery to detect changes over time. A reason for this is the challenge of comparing digital numbers (DN) from one satellite

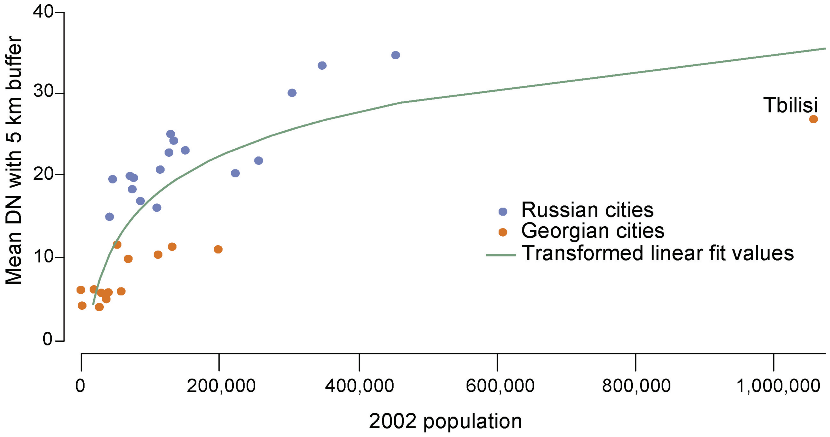

Fig. 3. Nighttime lights versus population for 31 cities in the Russian North Caucasus and Georgia, 2002.

pass to another since the on-board gain setting is adjusted dynamically (but not recorded) based on solar elevation, lunar phase, and elevation (Elvidge et al., 2004, 2009b). Elvidge et al. (2009b) address this variability in the nightlights data by intercalibrating the annual composites using Sicily, Italy as a stable region with an even spread of DNs across the dynamic range (0–63 DN). To do this, they fit a second-order regression model to calibrate all annual composites to 1999 (satellite F12), which exhibited the greatest pixel saturation (DN = 63). The resulting calibrated data were then used to track global natural gas flaring from 1994–2008 by country.

Another nighttime lights change detection study used individual scenes to detect the 2007 U.S. military surge in Baghdad (Agnew et al., 2008). One assumption that this study makes is that "the presence of nighttime light denotes a population with access to electricity, providing an indicator of relative quality and stability of everyday life" (ibid., p. 2288). While this is most often the case in urban areas, fires are also detected by the sensor, a special concern for ongoing war environments. It is thus possible that the decline in nighttime lights after the surge that the authors find reflects, in part, extinguished fires on the outskirts of Baghdad. Their conclusions, however, are based on direct comparison of digital numbers from one time period to the next. While this approach is tempting, it does not take into account potential differences in sensor gain settings between different satellite passes.

Radiometric Normalization

For this study, we develop a regional radiometric normalization method to account for variation in gain settings, sensor degradation, and atmospheric conditions. Such calibration is necessary for any change detection study wishing to directly compare digital numbers for a given locale (Song et al., 2001). Our approach relies on manual selection of pseudo-invariant features (Schott et al., 1988; Hall et al., 1991) which, for nighttime lights imagery, equates to identifying urban areas with a relatively constant level of lighting for the duration of the study period. The statistical distribution of the pixel DNs associated with these stable cities and towns is then used to normalize the war-affected areas of interest by converting those pixels to the standard normal distribution, or *z*-score. Because the number of satellite passes contributing to the monthly and annual composite data varies over the study area, the normalization calculation was weighted by the number of satellite passes contributing to each pixel.

The equations for the weighted mean, $\bar{x}_w$, and weighted standard deviation, S_w, are:

$$\bar{x}_w = \frac{\sum w_i x_i}{\sum w_i} \qquad s_w = \sqrt{\frac{\sum w_i (x_i - \bar{x}_w)^2}{\frac{(N-1)\sum w_i}{N}}},$$

where x_i is the DN for each pixel in the normalization set, w_i is the corresponding number of satellite passes contributing to the mean DN composite value, and N is the total number of normalization pixels. These weighted means and standard deviations are calculated for each monthly and annual composite, and then used to normalize all pixels in the composite, x_j, by calculating a *z*-score, z_j, for each pixel:

$$z_j = \frac{x_j - \bar{x}_w}{s_w}.$$

To select the normalization pixels, we identified pseudo-invariant cities by looking initially at the population census data reported above in Tables 1 and 2. The percentage change in population from 1989 to 2002 in these tables was used to help select cities with a stable nighttime light signature. In addition to the census population change data, we used a cross-validation technique to ensure each city's nighttime lights trend was stable over time. The stability of each city was evaluated by removing it from the set of stable cities and using the remaining cities to normalize its nighttime lights. This additional check prompted us to remove the Georgian cities of Batumi, Poti, and Tbilisi, whose lighting trend was noticeably brighter starting in 2005. The Russian cities of Budennovsk, Essentuki, Georgiyevsk, and Mineral'nyye Vody were also dropped from the stable cities list due to a gradual decrease in their normalized nighttime lights. Similar to the above lights and population analysis, we used the DCW populated places polygons to define the urban areas and expanded them using a 5 km buffer to capture surrounding lights. The 12 stable cities and their 5 km buffers (Fig. 1) constitute 3,671 pixels (*N* in the weighted standard deviation equation) used in the normalization process.

Conflict-Related Nighttime-Lights Trends

An initial time-series animation of the annual composite imagery revealed a clear increase in nighttime lights brightness around Grozny in 2000 and 2001. These increases are attributable to extensive oil fires that burned for months during this time. Retreating rebels began setting oil wells on fire in December 1999 (ITAR-TASS, 1999a), with as many as 40 oil well fires still burning in early 2001 (Interfax, 2002). In total, over 150 oil fires were extinguished from 2000–2002 during the most intense fighting of the second Chechen war (Russian Channel One TV, 2004). To visualize this

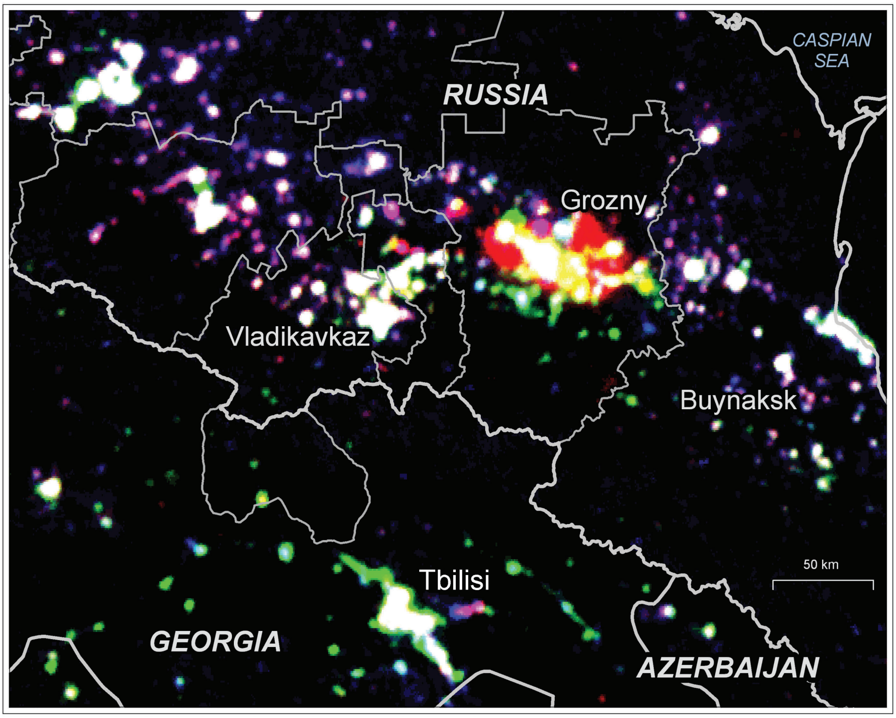

Fig. 4. False color composite (red = 2000, green = 2009, blue = 1997) shows fires around Grozny in 2000 (red) and the 2007 reconstructed highway northwest of Tbilisi (green). White lights indicate stable lighting over time. The image was constructed using normalized annual composites with each color band stretched identically.

increase in nighttime lights, we radiometrically normalized each annual composite by using the weighted mean and standard deviation of the pixels from the 12 stable cities to calculate *z*-scores for each pixel in the annual composites. The false color composite image in Figure 4 clearly shows these oil fires around Grozny in red.

We then used the normalized composites to calculate the nighttime lighting trend for the five largest cities in the North Caucasus not already included in the set of normalization cities. These cities experienced sizeable population shifts (Grozny's population decreased, the other four increased), largely due to the violence during this period. Figure 5A shows the mean *annual* (1992–2009) normalized lighting trend for just the core pixels defined by the DCW populated places polygons whereas Figure 5B explores the detailed *monthly* lighting trends for the first two years of the second Chechen war (October 1999–January 2002). Figure 6 expands the area of interest by adding a 10 km buffer to the core city polygons (Fig. 1). The 10 km buffer is large enough to encompass portions of the burning oil well fires shown in Figure 4. The higher overall *z*-score values of Figure 5 indicate the core lights of these cities are about 1–3 standard deviations above the set of normalization city pixels, in contrast to the buffered cities of Figure 6 that include more dark pixels in the mean DN calculation.

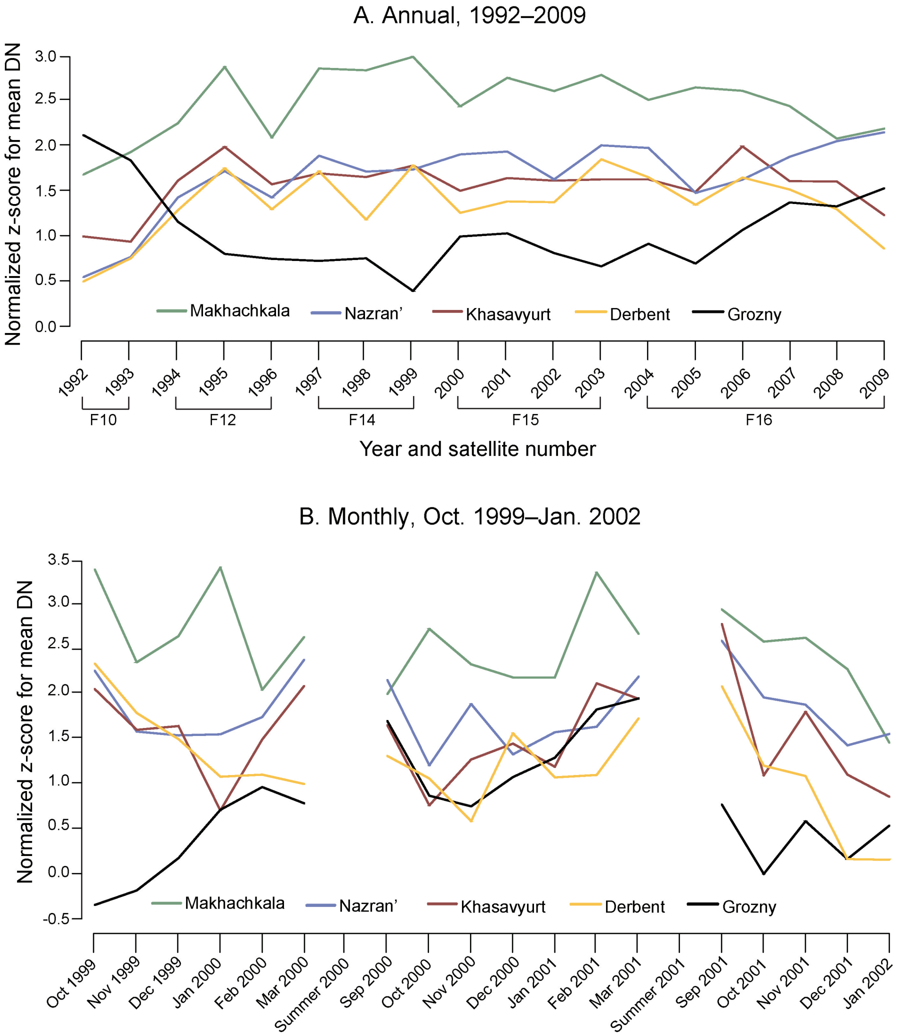

Fig. 5. North Caucasus large cities (core pixels) annual and monthly normalized nighttime lights trends.

Though the impact of the oil fires of the second Chechen war on the lighting for the Grozny urban core (Fig. 5A) was weak, the fires are strongly evident in both 2000 and 2001 when surrounding nighttime lights are included (Fig. 6A). During the first Chechen war (1994–1996), the Russian army was careful not to attack oil refineries or wells, in contrast to the second Chechen war, when rebels specifically targeted refineries, oil wells, and a petrochemical plant as part of a strategy to prevent their use by the Russian government (Vatchagaev, 2008). Despite the relative protection of oil infrastructure in the first war, Figure 6A still shows a modest increase in nighttime lights around Grozny in 1996, evidence of oil fires that burned for several weeks outside the city (Gall, 1997). The monthly data of Figure 6B provides a more detailed picture

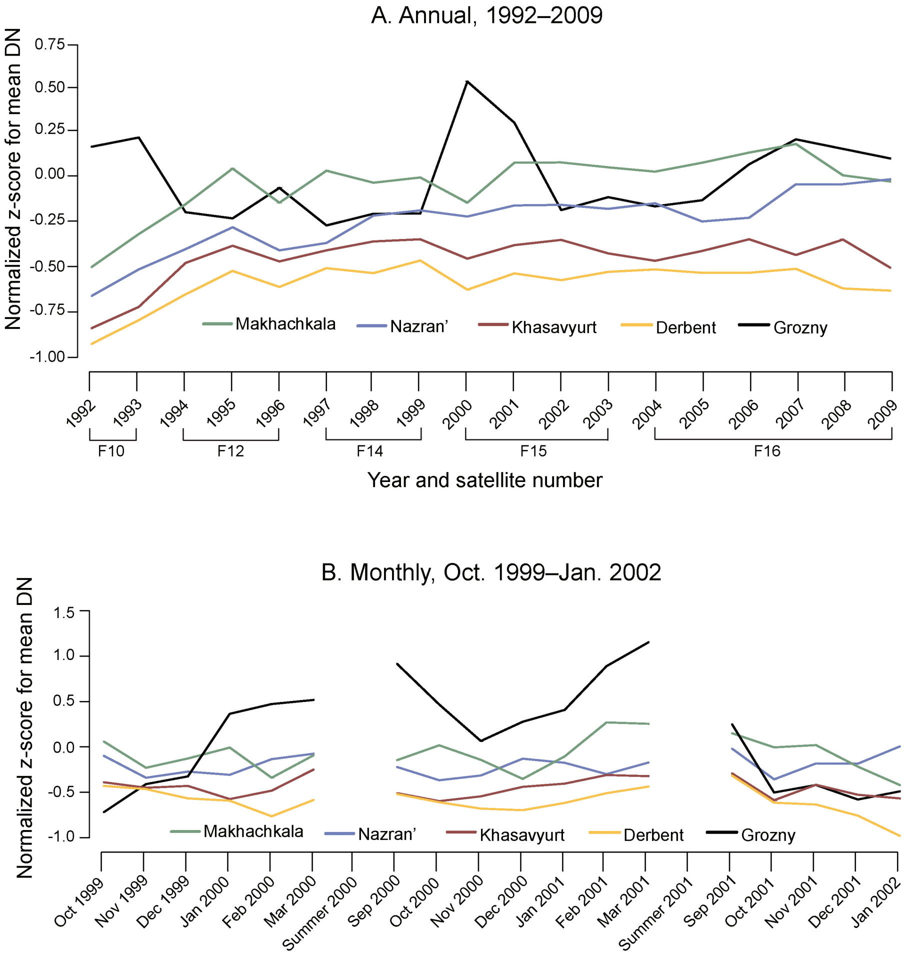

Fig. 6. North Caucasus large cities with a 10 km buffer annual and monthly normalized nighttime lights trends.

of the oil fires during the start of the second Chechen war, with the worst of the fires extinguished by October of 2001.[7]

The stark decline in nighttime lights for Grozny at the start of the first Chechen war in 1994 is associated with the population fleeing the city and the destruction of electrical infrastructure (Fig. 5A). Grozny's 1992 brighter core compared to Makhachkala is expected given the 1989 Russian census data showing Grozny with 82,491 more people (Table 1). The additional lighting drop in 1999 reflects the destruction of the energy supply system at the end of the year (RIA Novosti, 2000), though much of the damage was repaired in early 2000 (Manenkov and Kharchenko, 2000). These repairs

---

[7] Note that the summer gaps in Figures 5B and 6B are caused by solar interference during the evening when the satellites pass overhead.

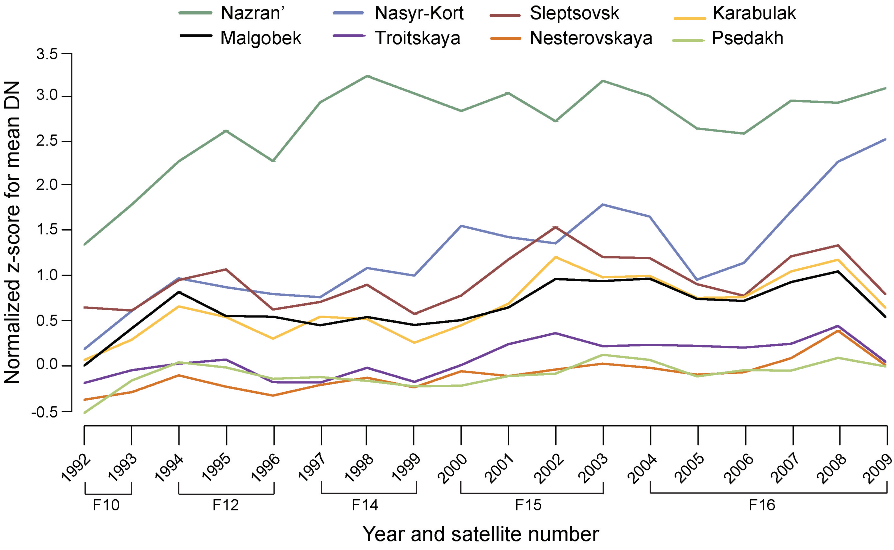

Fig. 7. North Caucasus refugee towns annual normalized nighttime lights trends (2.5 km buffer).

are visible in the quick rebound of the monthly nighttime lights signal (Fig. 5B), but some of the increase may be attributable to nearby oil fires or burning structures.

Grozny's dimmer core lights in 2000–2002 compared to Derbent (population 101,031) provides evidence that the Danish Refugee Council's survey population (67,212) more accurately reflects Grozny's true 2000–2002 population than the official Russian census figure (210,720). The increase in Grozny's lights since 2006 reflects the huge reconstruction effort initiated by then–Russian President Vladimir Putin as part of an economic development program for the region, though a portion of the funds were diverted by local corrupt leaders (The Economist, 2006, 2007).

We explore the impact of refugees from the second Chechen war in more detail by comparing the annual nighttime lights signal of the largest refugee destination towns (Fig. 7). We included these towns if 5,000 or more refugees were recorded by the Danish Refugee Council in September 2000 (Danish Refugee Council, 2000). Because most of these towns are small in population and several are close in proximity to each other (Fig. 1), we used the center latitude and longitude coordinates to geolocate each town (Falling Rain Genomics, 2010) (instead of the DCW polygons) and applied a 2.5 km buffer to evaluate the nighttime lights trends.

The towns that recorded the greatest number of refugees were Sleptsovsk (37,946), Karabulak (24,323), Nazran' (11,661), and Malgobek (10,819) at the end of 2000 into 2001 (Danish Refugee Council, 2000, 2001) (see Fig. 1 for locations). The other four towns all registered between 5,000 and 8,000 refugees. The two largest refugee destinations, Sleptsovsk and Karabulak show a clear increase in nighttime lights starting in 2000 and peaking in 2002 (Fig. 7). Malgobek and Troitskaya also register increases in lighting, but not as substantial. The lighting trends for these cities reflect the increase in population after fighting broke out, and then the decrease in refugee numbers beginning in 2002 (Danish Refugee Council, 2002) as the Russian government began to close camps (Weir, 2002), an effort that lasted well into 2004 (Mite, 2004). Despite a sizable influx of refugees in 2000, Nazran' does not show an increase in nighttime lights at this time. This is likely due to the large size of Nazran', and its ability to absorb refugees into existing housing with little additional construction. Also, Figure 3 shows Nazran' with its 2002 population of 125,000 and nighttime lights DN of 25.3 well above the fitted curve, indicating the city already emits more light than expected for its given population. Nasyr-Kort, located just to the southeast of Nazran' (Fig. 1), also shows an increase in nighttime lights after 1999, but particularly in 2008 and 2009. The recent increase in nighttime lights is likely associated with construction of the new Ingushetian capital of Magas, located just to the south of Nasyr-Kort.

To further explore the effects of refugee movement in the Caucasus region, we calculated nighttime light trends for the main cities and towns in South Ossetia and Georgia (Fig. 1) that were affected by the 2008 war either directly by the fighting (Tskhinval(i), Kurta, and Gori) or indirectly by an influx of refugees (Tserovani, Kvemo Bolnisi, Lagodekhi, Shaumiani, and Surami). For towns receiving refugees, we used the same 5,000-person threshold from the Chechen wars using data from a 2009 UNICEF report (see Appendix A in ACF/IRC and UNICEF, 2009). Figure 8A shows the annual weighted normalized nighttime lights trends for pixels within 2.5 km of these locations.

Gori and Tskhinval(i) are the largest cities and so appear brightest overall. We initially expected to see a decline in 2008 for these cities due to power outages and a reduced population associated with the war; Gori appears to meet this expectation, but no decline in nighttime lights is visible for Tskhinval(i), which saw the heaviest fighting. As noted above, the power in Tskhinval(i) was restored by the end of August 2008 (Ekho Moskvy Radio, 2008). Since the first nighttime lights satellite data are not available until October 2008 due to the long summer days interfering with nighttime lights data collection, the power outages during the war went undetected. Russia, South Ossetia, and charities have invested substantially in Tskhinval(i), constructing a new sports complex and rebuilding apartment complexes, government buildings, schools, and the hospital (Gritchin, 2009; RIA Novosti, 2009; News Agency of the Republic of South Ossetia, 2010). The new roofs (typically red) from these buildings are clearly visible from the hillsides above Tskhinval(i) and from satellite imagery in Google Earth, though the aerial view obscures much of the damage that persists from both the 1992 and 2008 wars (RIA Novosti, 2009).

Kurta, an ethnic Georgian village north of Tskhinval(i) destroyed during the conflict, experienced a noticeable decline in nighttime lights for 2009, indicative of the destruction pictured in Figure 2. This decrease corresponds to almost no lights in the village; the pixels over the town of Kurta have a 2009 DN value of 3, which is below the threshold used to remove background noise pixels for this region (Baugh et al., 2010). This nighttime light disappearance also occurred for towns east of Tskhinval(i) (e.g., Argvitsi, Berula, and Eredvi) that were also completely destroyed in the aftermath of the 2008 war (UNITAR, 2008c).

To explore the 2008 reduction in Gori brightness, we purchased additional monthly scenes for the first available months (actually lunar cycles) immediately following the war in 2008, and similar months in 2007 and 2009 for comparison. Figure 8B graphs the normalized nighttime lights values for these months and shows a small postwar decline for Gori. The dramatic 2006 increase in nighttime lights for Gori

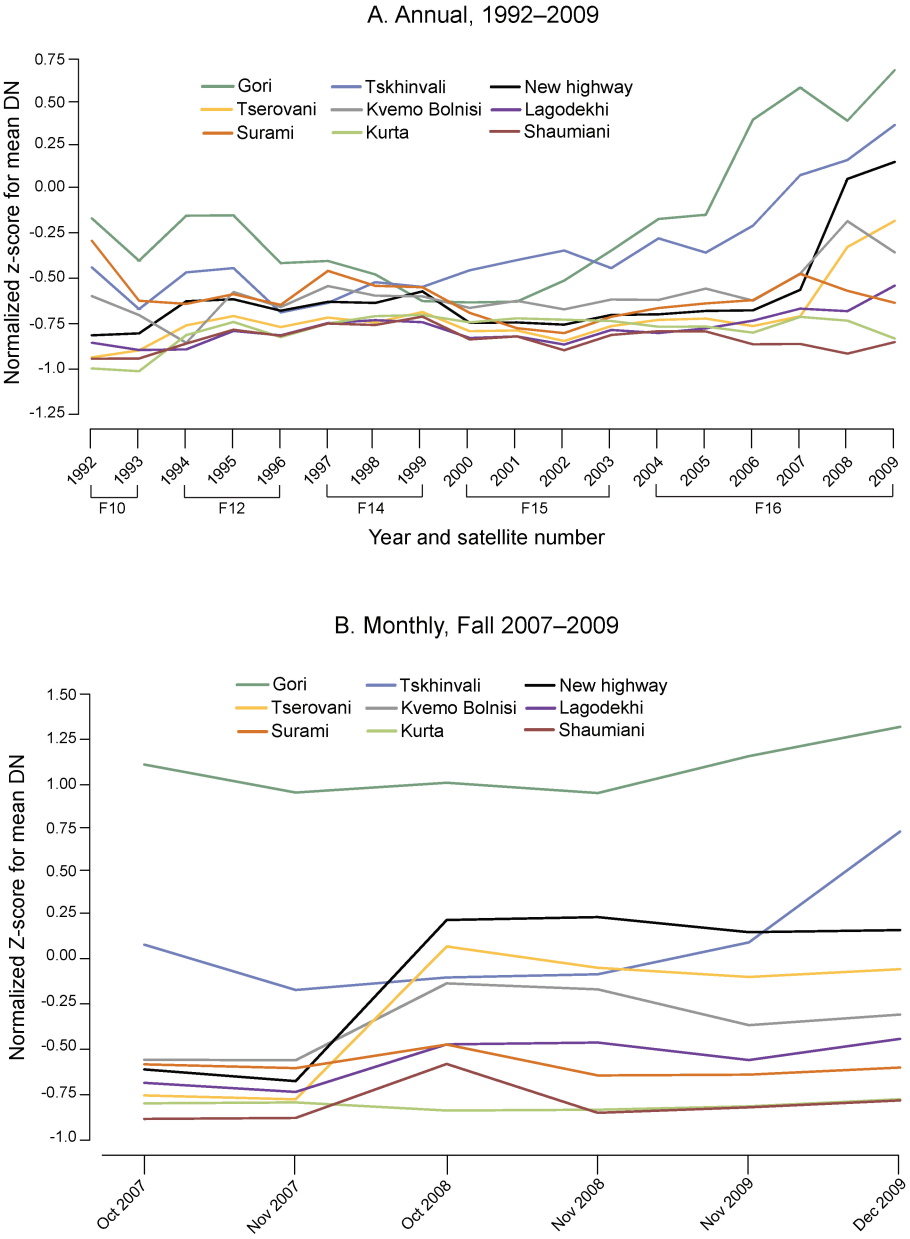

Fig. 8. South Ossetia and Georgia towns annual and selected monthly normalized nighttime lights trends.

is attributable, in part, to the opening of the Central Military Hospital (Ministry of Defense of Georgia, 2006) and a new NATO-standard military base with barracks for 5,000 personnel and covering 70 hectares (Tsimakuridze, 2008). Construction of the base began in 2006 and was opened in January 2008. The military base and other buildings in Gori were heavily damaged during the South Ossetian war, explaining the decline in nighttime lights for 2008. Construction of new housing for refugees also contributes to the recent increase in nighttime lights (The Georgian Times, 2010).

For the cities that received refugees, we expected to see an increase in nighttime lights following the war. This expectation holds for most cities except Surami (Fig. 8A), located next to the larger city of Kashuri, whose brightness may be overwhelming any increased brightness experienced in Surami. The monthly trends immediately following the war show a clear increase in brightness for many of the refugee cities in October 2008, though only Lagodekhi and Kvemo Bolnisi sustain the brighter levels through November 2008. Tserovani, a refugee settlement often identified as a model development with 2,000 new houses (Mainville, 2009), appears to have dramatically increased its lighting following the war (Fig. 8). This result, however, may be spurious due to the near simultaneous construction of the Natakhtari-Aghaiani section of the Tbilisi-Sokhum(i) highway, which opened 6 December 2007 (Burjanadze, 2007). The line labeled "New highway" in Figure 8 shows there is no additional increase in Tserovani's brightness relative to the new highway.

CONCLUSIONS

Though nighttime lights satellite imagery do not have the high spatial resolution of some newer sensors, this research shows they are capable of detecting changes in lighting associated with violent conflict even at a relatively coarse resolution. Long-term oil fires and large refugee outflows were easiest to detect, though refugee inflows, even those of relatively small magnitude, were also detectable in both the North Caucasus and in Georgia. Refugee inflows can be difficult to detect because refugees often stay in existing housing or temporary camps with little electrification. When new settlements are constructed or abandoned ones rehabilitated, the impacts of refugees are easier to detect.

As seen in the 2008 South Ossetian war, detecting the immediate impacts from short-duration summer conflicts in high latitudes poses an additional challenge due to short nights and solar interference that limit the nighttime lights coverage. For conflicts occurring during non-summer months, however, the nighttime lights imagery can be used to supplement media reports to aid in the near real-time monitoring of war due to the nightly availability of nighttime lights data. Ongoing efforts to improve the quality of the existing digital DMSP-OLS nighttime lights imagery as well as to digitize older imagery from film archives will enhance the usefulness of this dataset to both current and past conflicts. This historical record (currently back to 1992) is one of the main advantages of using the nighttime lights imagery. Other reasons to use the imagery include its low cost (annual composites are free), global spatial coverage, and nightly temporal coverage.

The nighttime lights imagery can be used in conjunction with other techniques such as high-resolution imagery and individual event analysis to construct a more complete picture of the spatial and temporal conflict effects for a given region. The U.S. Holocaust Memorial Museum's Darfur mapping initiative (USHMM, 2009) is a good example of the effectiveness of satellite imagery in documenting the effects of conflict. This initiative provides hundreds of before and after images of destroyed villages via Google Earth. Mapping and analyzing individual violent events collected from media reports can also support satellite imagery in understanding the ebb and flow of conflict. This type of work has been done in the North Caucasus region (O'Loughlin and Witmer, 2011) as well as Afghanistan and Pakistan (O'Loughlin et al., 2010a, 2010b). Combining multiple sources of satellite imagery with the often partial and biased media reports can help provide a more accurate picture of the spatial and temporal distribution of violence, even in the "fog of war."

ACKNOWLEDGMENTS

The authors would like to thank Benjamin Tuttle at the National Oceanic and Atmospheric Administration (NOAA) for his assistance in acquiring the DMSP-OLS data and his comments on an earlier draft. Thanks also to Nancy Thorwardson for putting the finishing touches on the two maps. This research was made possible by funding from the National Science Foundation, grants 0433927 and 0827016 (John O'Loughlin PI) and the Robert N. Colwell Memorial Fellowship (to Frank Witmer) from the American Society for Photogrammetry and Remote Sensing (ASPRS).

REFERENCES

AAAS, 2010, "High-Resolution Satellite Imagery and the Conflict in South Ossetia," American Association for the Advancement of Science (AAAS) Science and Human Rights Program [http://shr.aaas.org/geotech/georgia/georgia.shtml], accessed February 8, 2011.

ACF/IRC and UNICEF, 2009, "Assessment of Situation, Needs, and Priorities for Water, Sanitation, and Hygiene in Georgia IDP Settlements," Action Contre la Faim, International Rescue Committee, UNICEF, June 12, 2009.

Agnew, J., Gillespie, T. W., Gonzalez, J., and B. Min, 2008, "Baghdad Nights: Evaluating the U.S. Military 'Surge' Using Nighttime Light Signatures," *Environment and Planning A*, 40(10):2285–2295.

Amnesty International, 2010, "Georgian Government Must Secure Future for Displaced," [http://www.amnesty.org/en/for-media/press-releases/georgian-government-must-secure-future-displaced-2010-08-05], accessed January 20, 2011.

Asmus, R., 2010, *A Little War That Shook the World: Georgia, Russia, and the Future of the West*, New York, NY: Palgrave Macmillan.

Baugh, K., Elvidge, C., Ghosh, T., and D. Ziskin, 2010, "Development of a 2009 Stable Lights Product Using DMSP-OLS Data," in *Proceedings of the 30th Asia-Pacific Advanced Network Meeting*, 114–130.

BBC News, 2009, "Russia 'Ends Chechnya Operation'," British Broadcasting Corporation [http://news.bbc.co.uk/2/hi/europe/8001495.stm], accessed July 22, 2010.

Brown, I. A., 2010, "Assessing Eco-Scarcity as a Cause of the Outbreak of Conflict in Darfur: A Remote Sensing Approach," *Internation Journal of Remote Sensing*, 31(10):2513–2520.

Burjanadze, N., 2007, "Natakhtari-Aghaiani Section of Tbilisi-Sokhumi Highway Opens," [http://www.parliament.ge/index.php?lang_id=ENG&sec_id=34&info_id=17732], accessed September 18, 2010.

Danish Refugee Council, 2000, "DRC/ASF Re-Registration of Chechnya IDPs in Ingushetia," September 2, 2000.

Danish Refugee Council, 2001, "DRC/ASF Re-Registration of Chechnya IDPs in Ingushetia," [http://www.reliefweb.int/library/documents/2001/drc-rus-30nov.pdf], accessed September 13, 2010.

Danish Refugee Council, 2002, "North Caucasus Situation Report No. 50, 30 June 2002," [http://www.reliefweb.int/rw/rwb.nsf/AllDocsByUNID/a98c85055545dfb2c1256c0000458467], accessed July 16, 2010.

Danko, D. M., 1992, "The Digital Chart of the World Project," *Photogrammetric Engineering and Remote Sensing*, 58(8):1125–1128.

Doll, C. N. H., Muller, J.-P., and C. D. Elvidge, 2000, "Night-Time Imagery as a Tool for Global Mapping of Socioeconomic Parameters and Greenhouse Gas Emissions," *Ambio*, 29(3):157–162.

Ekho Moskvy Radio, 2008, "Power Supply Restored in South Ossetian Capital, Says Russian Ministry," *BBC Worldwide Monitoring*, August 20, 2008.

El-Baz, F., and R. M. Makharita, 1994, *The Gulf War and the Environment*, Amsterdam, The Netherlands: Gordon and Breach Science.

Elvidge, C. D., Baugh, K. E., Dietz, J. B., Bland, T., Sutton, P. C., and H. W. Kroehl, 1999, "Radiance Calibration of DMSP-OLS Low-Light Imaging Data of Human Settlements," *Remote Sensing of Environment*, 68(1):77–88.

Elvidge, C. D., Baugh, K. E., Kihn, E. A., Kroehl, H. W., Davis, E. R., and C. W. Davis, 1997, "Relation between Satellite Observed Visible-near Infrared Emissions, Population, Economic Activity and Electric Power Consumption," *International Journal of Remote Sensing*, 18(6):1373–1379.

Elvidge, C. D., Safran, J., Nelson, I. L., Tuttle, B. T., Hobson, V. R., Baugh, K. E., Dietz, J. B., and E. H. Erwin, 2004, "Area and Positional Accuracy of DMSP Nighttime Lights Data," in *Remote Sensing and GIS Accuracy Assessment*, Lunetta, R. S. and J. G. Lyon (Eds.), Boca Raton, FL: CRC Press, 281–292.

Elvidge, C. D., Sutton, P. C., Ghosh, T., Tuttle, B. T., Baugh, K. E., Bhaduri, B., and E. Bright, 2009a, "A Global Poverty Map Derived from Satellite Data," *Computers & Geosciences*, 35(8):1652–1660.

Elvidge, C. D., Ziskin, D., Baugh, K. E., Tuttle, B. T., Ghosh, T., Pack, D. W., Erwin, E. H., and M. Zhizhin, 2009b, "A Fifteen Year Record of Global Natural Gas Flaring Derived from Satellite Data," *Energies*, 2(3):595–622.

Falling Rain Genomics, 2010, *Global Gazetteer Version 2.2*, Falling Rain Genomics, Inc. [http://www.fallingrain.com/world/index.html], accessed November 1, 2011.

Gall, C., 1997, "In Post-War Chechnya, Oil Is Key to Recovery," *The Moscow Times*, July 1, 1997.

Ghosh, T., Powell, R. L., Anderson, S., Sutton, P. C., and C. D. Elvidge, 2010a, "Informal Economy and Remittance Estimates of India Using Nighttime Imagery," *International Journal of Ecological Economics & Statistics*, 17(P10):16–50.

Ghosh, T., Powell, R. L., Elvidge, C. D., Baugh, K. E., Sutton, P. C., and S. Anderson, 2010b, "Shedding Light on the Global Distribution of Economic Activity," *The Open Geography Journal*, 3:148–161.

Gritchin, N., 2009, "Alina Kabaeva Brings Hope to Tskhinval," *Izvestia* [http://www.kabaeva-alina.com/press/media/2313/], accessed March 4, 2011.

Hall, F. G., Strebel, D. E., Nickeson, J. E., and S. J. Goetz, 1991, "Radiometric Rectification: Toward a Common Radiometric Response among Multidate, Multisensor Images," *Remote Sensing of Environment*, 35(1):11–27.

Holland, M., 2004, "Chechnya's Internally Displaced and the Role of Russia's Non-Governmental Organizations," *Journal of Refugee Studies*, 17(3):334–346.

Human Rights Watch, 2009, *Up in Flames: Humanitarian Law Violations and Civilian Victims in the Conflict over South Ossetia*. New York, NY: Human Rights Watch.

Husain, T., 1994, "Kuwaiti Oil Fires—Source Estimates and the Plume Characterization," *Atmospheric Environment*, 28(13):2149–2158.

Interfax, 2002, "Chechen Oil Well Fires Extinguished," *Interfax News Agency*, October 31, 2002.

ITAR-TASS, 1995, "Restoration of Chechen Oil and Power Sectors Continues," *BBC Summary of World Broadcasts*, October 27, 1995.

ITAR-TASS, 1999a, "Retreating Chechen Rebels Set Fire to Oil Wells—Russian Spokesman," *ITAR-TASS News Agency*, December 1, 1999.

ITAR-TASS, 1999b, "Russia: Energy Network Being Restored in Freed Chechen Areas," *BBC Worldwide Monitoring*, November 21, 1999.

ITAR-TASS, 2000, "Burning Oil Wells in Chechnya Being Put out Again," *BBC Worldwide Monitoring*, November 12, 2000.

Joiremon, S., 2012, "A Different Way Home: Resettlement Patterns in Northern Uganda," *Political Geography*, 32(2), in press.

Kavkazskiy Uzel, 2007, "Minoboron' RF: Za dve Chechenskiye kampanii pogibli 6.6 Tysyach voyennosluzhashchikh Rossii (Defense Ministry, Russian Federation: Two Chechen Campaigns Killed 6,600 Russian Troops)," [http://www.voinenet.ru/index.php?aid=13206], accessed June 8, 2010.

King, C., and R. Menon, 2010, "Prisoners of the Caucasus: Russia's Invisible Civil War," *Foreign Affairs*, 89(4):20–34.

Kron, J., 2011, "Signs of Razing in Contested Part of Sudan," *The New York Times*, March 7, 2011 [http://www.nytimes.com/2011/03/08/world/africa/08sudan.html], accessed March 9, 2011.

Kwarteng, A. Y., 1998, "Multitemporal Remote Sensing Data Analysis of Kuwait's Oil Lakes," *Environment International*, 24(1–2):121–137.

Mainville, M., 2009, "Georgia Refugees Adapt to Life in Settlement Camps," Agence France Presse [http://www.reliefweb.int/rw/rwb.nsf/db900sid/SNAA-7UK872], accessed September 18, 2010.

Manenkov, V. and A. Kharchenko, 2000, "Social Structures of Chechnya Restored," *ITAR-TASS News Agency*, March 15, 2000.

Mendelson, S. E., Malarkey, M., and L. Moore, 2010, *Violence in the North Caucasus: 2009, a Bloody Year*, Washington, DC: Center for Strategic and International Studies [https://csis.org/publication/violence-north-caucasus-5], accessed February 7, 2011.

Ministry of Defense of Georgia, 2006, "Opening Ceremony of the Military Hospital," [http://www.mod.gov.ge/index.php?page=772&type=0&lang=1&Id=339&p=48], accessed October 4, 2010.

Mite, V., 2004, "Russia: Chechen Refugees Face Ejection from Camps in Ingushetia," *Radio Free Europe/Radio Liberty*, January 14, 2004.

National Statistics Office of Georgia, 2010, [http://www.geostat.ge/index.php?lang=eng], accessed 11 Jun 2010.

News Agency of the Republic of South Ossetia, 2010, "Eduard Kokoity Visited Construction Sites in Tskhinval," Informatsionnoye Agentstvo Respublika Yuzhnaya

Osetiya (News Agency of the Republic of South Ossetia), accessed March 4, 2011.

Nichols, J., 2000, "The Chechen Refugees," *Berkeley Journal of International Law*, 18(24):241–259.

Norwegian Refugee Council, 2009, *Russian Federation: Monitoring of IDPs and Returnees Still Needed*, Geneva, Switzerland: Internal Displacement Monitoring Centre.

Ó Tuathail, G., 2008, "Russia's Kosovo: A Critical Geopolitics of the August 2008 War over South Ossetia," *Eurasian Geography and Economics*, 49(6):670–705.

O'Loughlin, J., Holland, E. C., and F. D. W. Witmer, 2011, "The Changing Geography of Violence in Russia's North Caucasus, 1999–2011: Regional Trends and Local Dynamics in Dagestan, Ingushetia, and Kabardino-Balkaria," *Eurasian Geography and Economics*, 52, in press.

O'Loughlin, J. and F. Witmer, 2011, "The Localized Geographies of Violence in Russia's North Caucasus, 1999–2007," *Annals of the Association of American Geographers*, 101(1):178–201.

O'Loughlin, J., Witmer, F., Dickinson, T., Thorwardson, N., and E. Holland, 2007, "Preface to the Special Issue and Map Supplement," *Eurasian Geography & Economics*, 48(2):127–134.

O'Loughlin, J., Witmer, F., and A. Linke, 2010a, "The Afghanistan-Pakistan Wars 2008–2009: Micro-Geographies, Conflict Diffusion, and Clusters of Violence," *Eurasian Geography and Economics*, 51(4):437–471.

O'Loughlin, J., Witmer, F., Linke, A., and N. Thorwardson, 2010b, "Peering through the Fog of War: The Geography of the WikiLeaks Afghanistan War Logs, 2004–2009," *Eurasian Geography and Economics*, 51(4):472–495.

Oak Ridge National Laboratory, 2008, "Landscan Global Population Dataset," [http://www.ornl.gov/sci/landscan/], accessed February 3, 2010.

Perepis, 2002, "2002 All-Russia Population Census," [http://www.perepis2002.ru/index.html?id=87], accessed June 11, 2010.

Prins, E., 2008, "Use of Low Cost Landsat ETM+ to Spot Burnt Villages in Darfur, Sudan," *International Journal of Remote Sensing*, 29(4):1207–1214.

RIA Novosti, 2000, "Vladimir Putin Firmly Intends to Start Restoring the Economy of Chechnya Which Has Suffered Tremendously from the Bandits," *RIA Novosti*, January 6, 2000.

RIA Novosti, 2009, "Tskhinval One Year On: It's as If the War Was Just Yesterday," RIA Novosti [http://en.rian.ru/analysis/20090805/155734070.html], accessed March 4, 2011.

Rowland, R. H., 2006, "National and Regional Population Trends in Georgia, 1989–2002: Results from the 2002 Census," *Eurasian Geography & Economics*, 47(2):221–242.

Russian Channel One TV, 2004, "Russian TV Shows Quenching of Last Chechen Oil Well Fire," *Russian Channel One TV*, January 8, 2004.

Russian Federation Federal State Statistics Service, 2010, "Goroda Chechenskoy Respubliki (Cities of the Chechen Republic)," accessed February 21, 2011.

Satellite Sentinel Project, 2011, "Satellite Sentinel Project Confirms Deliberate Burning of Third Village in Abyei Region," Satellite Sentinel Project, March 6, 2011 [http://www.satsentinel.org/press-release/satellite-sentinel-project-confirms-intentional-burning-third-village-abyei-region], accessed March 9, 2011.

Schimmer, R., 2008, *Tracking the Genocide in Darfur: Population Displacement as Recorded by Remote Sensing*, New Haven, CT: Yale University, Genocide Studies Working Paper No. 36.

Schott, J. R., Salvaggio, C., and W. J. Volchok, 1988, "Radiometric Scene Normalization Using Pseudo Invariant Features," *Remote Sensing of Environment*, 26(1):1–16.

Snoy, B., Bouvier, C., Swalley, D., Goldammer, J. G., Hanlon, W., Jicharadze, Z., and I. Rucevska, 2008, "Joint OSCE/UNEP Environmental Assessment Mission to Georgia 29 September—3 October 2008."

Soboleva, V., 2007, "Housing Project Brings Hope to Refugees in Caucasus, 17 October 2007," UNHCR [http://www.unhcr.org/cgi-bin/texis/vtx/search?docid=471625034], accessed July 16, 2010.

Song, C., Woodcock, C. E., Seto, K. C., Lenney, M. P., and S. A. Macomber, 2001, "Classification and Change Detection Using Landsat TM Data: When and How to Correct Atmospheric Effects?" *Remote Sensing of Environment*, 75(2):230–244.

Spotts, P., 2010, "George Clooney–Backed Satellite Project to Monitor Volatile Sudan," *Christian Science Monitor*, December 29, 2010.

Stephens, G. and M. Matson, 1993, "Monitoring the Persian Gulf War with NOAA AVHRR Data," *International Journal of Remote Sensing*, 14(7):1423–1429.

Sulik, J. J. and S. Edwards, 2010, "Feature Extraction for Darfur: Geospatial Applications in the Documentation of Human Rights Abuses," *International Journal of Remote Sensing*, 31(10):2521–2533.

Sunjic, M. H., 2008, "UNHCR Teams Enter Georgia-South Ossetia 'Buffer Zone'," [http://www.unhcr.org/48cfcb8b4.html], accessed August 25, 2010.

Suthakar, K. and E. N. Bui, 2008, "Land Use/Cover Changes in the War-Ravaged Jaffna Peninsula, Sri Lanka, 1984–Early 2004," *Singapore Journal of Tropical Geography*, 29(2):205.

Sutton, P. C., Ghosh, T., and C. D. Elvidge, 2007, "Estimation of Gross Domestic Product at Sub-National Scales Using Nighttime Satellite Imagery," *International Journal of Ecological Economics and Statistics*, 8(S07):5–21.

The Economist, 2006, "Richer, Bolder—and Sliding Back," *The Economist*, July 13, 2006.

The Economist, 2007, "The Warlord and the Spook," *The Economist*, May 31, 2007.

The Georgian Times, 2010, "Two Blocks of Apartments Constructed for IDPs in Gori," *The Georgian Times* [http://www.geotimes.ge/index.php?newsid=22627], accessed January 19, 2011.

Trier, T. and K. Deniev, 2000, "Chechnya in Figures: Survey of the Population of the Republic of Chechnya, Russian Federation, as an Instrument for Providing Targeted Humanitarian Assistance," Danish Refugee Council and ASF-Danish Peoples' Aid [http://www.reliefweb.int/rw/rwb.nsf/db900sid/OCHA-64CV2Y], accessed July 20, 2010.

Tsimakuridze, R., 2008, "New Military Base in Gori," *Georgia Today* (Defense Supplement) [http://www.mod.gov.ge/files/ijwtsgknrxgeo.pdf], accessed October 4, 2010.

UNEP, 2003, *Desk Study on the Environment in Iraq*, Geneva, Switzerland: United Nations Environment Programme.

UNEP, 2010, "Iraq Marshlands Observation System," United Nations Environment Programme [http://www.grid.unep.ch/activities/sustainable/tigris/mmos.php], accessed March 8, 2011.

UNHCR, 1999, "North Caucasus Update, 29 December 1999," [http://www.unhcr.org/cgi-bin/texis/vtx/search?docid=3ae6b80d38], accessed July 16, 2010.

UNHCR, 2000, "North Caucasus Update, 1 December 2000," [http://www.unhcr.org/cgi-bin/texis/vtx/search?docid=3ae6b80610], accessed July 16, 2010.

UNHCR, 2002, "North Caucasus: UNHCR Asks for Camp Closures Postponement, 29 November 2002," [http://www.unhcr.org/cgi-bin/texis/vtx/search?docid=3de75e2dd], accessed July 16, 2010.

UNHCR, 2008, "Revised Figures Push Number of Georgia Displaced up to 192,000," [http://www.unhcr.org/48ca8d804.html], accessed August 25, 2010.

UNITAR, 2008a, "Maps: Georgia," United Nations Institute for Training and Research (UNITAR) [http://www.unitar.org/unosat/maps/43], accessed March 7, 2011.

UNITAR, 2008b, "Update 2: Active Fire Locations for Tskhinvali, South Ossetia, Georgia," United Nations Institute for Training and Research (UNITAR) [http://www.unitar.org/unosat/node/44/1247], accessed March 7, 2011.

UNITAR, 2008c, "Village Damage Summary: Eredvi, Berula & Argvitsi, South Ossetia, Georgia," United Nations Institute for Training and Research (UNITAR) [http://www.unitar.org/unosat/node/44/1282], accessed March 4, 2011.

USHMM, 2009, "Mapping Initiatives: Crisis in Darfur," United States Holocaust Memorial Museum [http://www.ushmm.org/maps/projects/darfur/], accessed February 8, 2011.

van Etten, J., Jongerden, J., de Vos, H. J., Klaasse, A., and E. C. E. van Hoeve, 2008, "Environmental Destruction as a Counterinsurgency Strategy in the Kurdistan Region of Turkey," *Geoforum*, 39(5):1786–1797.

Vatchagaev, M., 2008, "Oil in Chechnya: A Brief History," *North Caucasus Analysis*, 9(15) [http://www.jamestown.org/single?no_cache=1&tx_ttnews[tt_news]=4870], accessed November 1, 2011.

Vendina, O. I., Belozerov, V. S., and A. Gustafson, 2007, "The Wars in Chechnya and Their Effects on Neighboring Regions," *Eurasian Geography and Economics*, 48(2):178–201.

Weir, F., 2002, "Russia Says 'Return', but Chechen Refugees Stay Put," *The Christian Science Monitor*, February 5, 2002.

Wendle, J., 2008, "Fanning Ethnic Flames in Georgia," *Time.com*, August 20, 2008 [http://www.time.com/time/world/article/0,8599,1834182,00.html], accessed February 8, 2011.

Williams, R. S., Heckman, J., and J. Schneeberger, 1991, *Environmental Consequences of the Persian Gulf War, 1990–1991: Remote-Sensing Datasets of Kuwait and Environs*, Washington, DC: National Geographic Society.

Witmer, F. D. W., 2008, "Detecting War-Induced Abandoned Agricultural Land in Northeast Bosnia Using Multispectral, Multitemporal Landsat TM Imagery," *International Journal of Remote Sensing*, 29(13):3805–3831.

World Bank, 2009, "GNI Per Capita, Atlas Method (Current US$)," [http://data.worldbank.org/indicator/NY.GNP.PCAP.CD], accessed August 24, 2010.

Zürcher, C., 2007, *The Post-Soviet Wars: Rebellion, Ethnic Conflict, and Nationhood in the Caucasus*, New York, NY: New York University Press.